An Investigation of Presence Response across Variations in Visual Realism

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Abstract

This paper describes reports on the results of an experiment designed to study the impact of realism on the reported presence in an immersive virtual environment. An experiment was carried out with 40 participants who were asked to walk through a virtual street, which had virtual characters walking through it. Two factors were varied – texture quality (2 levels) and virtual character realism (2 levels). 10 participants were assigned to each cell, which was also balanced for gender. The results suggest that the lowest presence was achieved with the higher fidelity characters but the less varied textures. Other factors such as perceived realism of character behaviour were important. Finally a system called PIAVCA for virtual character control is introduced which was used in conjunction with DIVE [25, 29].

Keywords--- **Virtual Environment, Textures, Virtual Characters, Visual Realism, Presence.**

1. Introduction

Even with the current state-of-the-art technology available to us, it is difficult to design and implement a believable virtual environment. Traditionally it has been assumed that the more believable virtual experiences are constructed by making the environment as visually realistic as possible [9]. However a fundamental difficulty in achieving total visual realism is the complexity of the real world. The richness of the real world is observable in the surface textures, subtle colour gradations, shadows, reflections, and the slight irregularities in the surrounding objects [8].

On the other hand it is equally arguable that even simulations with a lower degree of realism can still contain the more important information necessary to give a believable experience such as those perceived in flight simulators or in stressful scenarios [18, 32]. We present a study that focuses on trying to explore various features that enhance reported presence in an immersive virtual environment (IVE). In particular we aimed to explore the impact of different texture quality and visual realism of virtual characters on the overall level of presence in a populated urban virtual environment (VE).

2. Objectives

Our main goal was to investigate whether there needs to be consistency between the levels of realism of the different elements within a scene. In this case this means whether the level of realism of the buildings needs to be consistent with the level of realism of characters populating the environment. Our interests in this study were three-fold.

- Firstly to investigate the relationship between reported presence and the variety of textures on the buildings in the scene.
- Second, the impact of the visual realism of the virtual characters on reported presence.
- Third, to investigate whether there needs to be consistency between the levels of realism of the different elements within the scene.

We hypothesised that less repetitive textures in the scene and more lifelike characters will enhance the participants' presence experience in the virtual world. We vary visual realism of the IVE by altering the number of textures used on the buildings and by using two types of virtual characters in the study. Although both types of virtual characters were not visually realistic in terms of their human appearance, one was deliberately designed to be cartoon-like, and the other to have an appearance that was more realistic. For example, the second kind had a face that was texture-mapped from real human faces. We call the more realistic type 'higher fidelity' (HF) and the other form 'cartoon form' (CF). We will use these terms in the remainder of this paper.

We also wished to ascertain if there was an interaction effect between the visual realism of the character and the richness of texture variety of the environment. This was especially important, because earlier research [12] indicates that consistency is required between virtual character behaviour and appearance. Here we wished to see if this extended to consistency between environmental and virtual character realism.

A subsidiary goal was to investigate the correlation between three measures of presence: stress response measure by heart-rate variability, breaks in presence as measured by verbal report, and self-report questionnaires. We also used this study to test Platform Independent API for Virtual Characters and Avatars (PIAVCA) in conjunction with DIVE[1] [25, 29].

3. Background

It has been claimed that however visually appealing a virtual environment is, if it is static and empty of change and behaviour, the immersive experience is of limited interest to the participants [3]. In *Neil Stephenson's* Snow Crash [27], surroundings in the Metaverse are highly photo-realistic while characters are *both* visual realistic and expressive depending on the status of the owner. In fact both visual and behavioural realism perform seamlessly in real-time to produce a life-like experience.

Even though it is possible to generate visually realistic virtual environment and characters [1], one of the main constraints preventing the usage of these highly realistic models is the higher expectations of participants leading to increased sensitivities to inconsistencies in the VE [30]. It is not only the shape of virtual bodies that matter in the experience of virtual environments but also the level of detail with which they are represented [19]. Another major constraint is the tension between realism and real-time [11]. This constraint is of particular importance in larger environments due to the increased demands made on graphics cards.

It has been established that in order to enable participants to experience acceptable levels of presence in VEs, the virtual characters have to portray some level of non-verbal behaviour. This has been found in a series of studies involving interaction between three participants in a shared VE [22, 26, 30]. Tromp et al. concluded that higher visual realism in characters may lead to a heightened expectation for behavioural realism [30]. In particular in [28] there is anecdotal evidence that participants expect more photo-realistic characters to behave in a manner, which portray greater human-like qualities. What seems to be important is that visually realistic worlds and characters have similar levels of behavioural realism [11, 12].

The issue of consistency within a scene can be traced back to works as early as Gibson [13, 14]. One insight recent that a recent study has provided is that pictorial or visual realism is not sufficient and sometimes not necessary to create a sense of presence or co-presence [12]. This is partially supported by work done by Longhurst et al [17], where studies showed artistically enhancing an image through the addition of dust, dirt and scratches increases the perceived realism of an image. In another study [6], carried out to explore the visual elements necessary to make an effective VE, it has been suggested that improving visual realism in a VE is not just about rendering flawless models.

The current study focuses on the perception of realism in urban virtual environments. It was designed to explore three aspects important to create a believable virtual environment: sense of space, realism of textures in VE and degree of visual realism of characters.

[1] Distributed Interactive Virtual Environment

4. The Experiment

4.1. Factorial design

Our study was designed to assess some limits of visual realism in enhancing the believability of virtual environments.

We choose to study two factors:

- The level of detail employed in our VE with respect to the number of textures used;
- The visual realism of the inhabiting characters.

A gender-balanced between-group two-by-two factorial design was used in the experiment.

	Cartoon Form (CF) Characters	**Higher Fidelity (HF) Characters**
Repetitive Textures	5 males + 5 females	5 males + 5 females
Non-Repetitive Textures	5 males + 5 females	5 males + 5 females

Table 1: Factorial Design of the Experiment

Forty participants were assigned at random to one of the four conditions as illustrated in Table 1. Participants were recruited by poster campaigns across the university and paid £5 to take part in a one-hour study.

4.2. The virtual environment

A virtual world was created in 3D Studio MAX to resemble a typical street-like environment. One of the factors in the study was dependent on the number of different textures used in the scene. In the conditions with "*Repetitive Textures*", 20 different textures were used to provide shop billboards and fronts whereas in the conditions involving "*Non-Repetitive Textures*" there was twice the number of textures (~40).

Figure 1: The *Street*.

The environment consisted of a high street lined with buildings on either side with a few secondary streets off the main street. The ends of the main and the secondary streets were sealed off in order to force the participants to stay within the limits of the designed world. A few tall buildings were modelled in the horizon outside the peripherals of the street to maintain the illusion of a curtained off the high street. The same street model was used throughout the experiment with the only difference being the number of different textures used.

4.3. The characters

The second factor varied in the study was the visual realism of the characters. There were two types of characters used: cartoon form (CF) (Figure 2) and higher fidelity (HF) (Figure 3). All the characters were H-Anim [31] complaint humanoids. All the characters were animated to walk using the same motion file and given the same behaviour.

The characters were animated to walk out onto the street through one of four doors at the ends of the main street. The character walked to the opposite end of the street using a cyclic walk pattern defined by the motion file taking care to avoid each other and the participant undergoing the study. Each character started walking at slightly different times so that the animation of the characters did not appear synchronised. The only varying factor between conditions was in the visual appearance of the characters.

The street was populated with a total of 16 virtual characters walking up and down the main street however only 8 characters were on the street at any one time. The decision to activate only 8 characters in IVE at the same time was made due to a technical constraint in rendering all the characters in run-time at an acceptable frame rate.

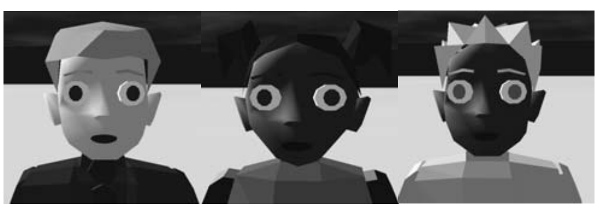

Figure 2: The cartoon form characters.

Figure 3: The higher fidelity characters.

4.4. Software implementation

The software used was implemented on a derivative of DIVE 3.3x [10]. This was recently ported to support spatially immersive systems [25]. DIVE (Distributed Interactive Virtual Environment) is an internet-based multi-user virtual reality system in which participants can navigate in a shared 3D space and interact with each other. Plugins make DIVE a modular system. DIVE also supports the import and export of VRML and several other 3D file formats. The VE used was created in 3D Max and exported to VRML.

The characters were animated using PIAVCA, the Platform Independent API for Virtual Character and Avatars. This is a character animation library that is designed to be independent of any underlying graphics engine, and which has been ported to DIVE. PIAVCA is able to animate characters using motion data stored in Biovision BVH format. BVH is a file format for representing human motion in a form that is independent of the character that performs this motion. This enables a single piece of motion to be applied to multiple characters. The motions data can either be acquired through motion capture or hand animation, for this study we used walking motion from a motion capture library. As well as simply playing animation data PIAVCA has a number of facilities for manipulating and sequencing motions. There are a number of methods of manipulating the pieces of motion, including smoothly sequencing motions into each other, interpolating between motions, and manipulations of individual motions such as turning a motion through an angle. A callback system is also available to sequence new motions at appropriate times.

A callback was used to animate the characters walking down the street and avoiding collisions with each other and the participant. A piece of motion representing a single footstep was used. At the end of each footstep the callback determined whether evasive action was required in the next footstep. Each character was aware of the position of each of the other characters. The position of the participant was sensed by DIVE and with this information the participant was treated as another character. If any of the other character or the participant were in the path of the character it would alter its path, using PIAVCA motion manipulations to smoothly step to one side. The same callback would also ensure that the character would remain on the street. If no evasive action was required a normal straight footstep was chosen. If a character reached the end of the street it would walk into a shop entrance and then become inactive.

4.5. Equipment

A CAVE™-like [7] Immersive Projection Technology (IPT) system, referred to as a ReaCTor, was used to generate our IVE. The Trimension ReaCTor used in the study, consisted of three 3m x 2.2m walls and a 3m x 3m floor. It was powered by a Silicon Graphics Onyx2 with 8 300MHz R12000 MIPS processors, 8GB RAM and 4 Infinite Reality2 graphics pipes. This machine processed all the graphics and audio input pertaining to the ReaCTor. The participants wore CrystalEyes stereo glasses, which were tracked by an Intersense IS900 system accurate to within 2mm with an end-to-end latency of 50ms. The ReaCTor runs at a maximum refresh rate of 45Hz in stereo. In the remainder of this paper we will use the term ReaCTor to refer to this system.

4.6. Procedure

Due to the complex procedure in the study, two experimenters guided the participants through the study. On arrival for the study the participants were asked to sign a consent form, which gave them information about the equipment, an outline of what the study involved and informed them of possible negative effects from using the system such as simulator sickness. They were told that they could withdraw from the study at any time without giving a reason, and that they agree not to drive or operate complex machinery for at least 3 hours after the conclusion of the study.

The participant was then given an online questionnaire asking them to provide information about their background for demographic purposes. They were also asked to fill in a memory questionnaire designed to assess how the participant recalled a physical surrounding they had been in earlier that day. The participant was then given a short training to help in understanding the concept of "breaks in presence (BIPs)" [4]. In this training they were asked to look at four Gestalt pictures and switch their focus from one perceived image to the other. The *transitions* they experience in the viewing exercise were equated to transitions they might feel to the real world of the laboratory while in the virtual environment. Through out the study, BIPs were referred to as "*transitions to real*".

Figure 4: A participant in the ReaCTor.

The participant was then invited to step into the ReaCTor and the experimenters fitted the participants with physiological sensing devices to collect the participants' Electrocardiogram (ECG), Galvanic Skin Responses (GSR) and Respiration measures. The participant was then asked to stand still and quiet in the darkened ReaCTor for a full minute and a half. This was necessary to gather readings about each individual participant while they are *inactive* in order to have a baseline to compare physiological readings taken during the study. At the end of the minute and a half, a virtual training room containing three-dimensional numbers appeared on the walls of the ReaCTor. One of the experimenters showed the participants how to move through an environment moving from number to number. At the end of the training, the participant was told to exit through a door onto the *street* and to do as they pleased for a few minutes. We wanted the participant to notice any anomalies in the virtual environment and point it out in the post-session debriefing. At the same time, we felt it would not be wise to ask the participant to look for anything in particular since this might make the participants more interested in completing the task than getting involved in the experience. They were also asked to signal any *transitions to real* that they felt by pressing a button on the joystick they used for navigation. At this stage, the experimenters left the participant in the ReaCTor and *opened* the virtual door leading to the street (Figure 1).

While the study was in progression, the experimenters maintained silence and observed the behaviour of the participant in the VE. The participants were also videotaped during the study. At the end of 3 minutes, the global lights in the street were switched off and a target light was activated to point the participant in the direction of the training room.

The participant was then asked an immediate question asking them to access how *present* they felt overall in the street. The result from the immediate questionnaire is used in analysing the number of BIPs reported by the participant [23]. The participant was then asked to complete an online post-questionnaire designed to gather data on various matters including their subjective sense of presence (questions available in [23, 24]). They were also asked to fill in another memory questionnaire about the VE. An argument has been put forward that questionnaires are methodologically unsound for assessing presence when they are the sole instrument for assessment [20],. Hence in this study we have used questionnaires, post-experimental interviews, physiological measures, and BIPs. In this paper we concentrate largely on the questionnaire responses.

The session concluded with an audio taped semi-structured interview conducted by both experimenters with each participant.

5. Presence Measures

The sense of presence in the VE was evaluated by taking a number of measures, including questionnaires [16, 23], physiological measures [18], and reported breaks in presence (BIPs) during the experience [23].

5.1. Subjective

A variety of questionnaires were administered to assess the behaviour and views of the participants. Most of the questionnaires were administered online to each of the participant before and after their experience. We obtained responses on each of the following:

- *Demographics:* age, gender, occupation, language proficiency, experience in computer games, programming and virtual reality etc.

- *Presence:* A total of 11 questions of which 5 were from the Slater-Usoh-Steed (SUS) questionnaire [23, 24] and 6 were from the ITC Sense of Presence Inventory (ITC-SOPI) [16].
- *Others:* Participants' perceived realism of the street, perceived visual realism and perceived behavioural realism of characters, perceived expressiveness of the characters, level of co-presence felt, level of reported interaction with the characters.

5.2. Physiological

Physiological measures were recorded during the participant's experience, using non-invasive devices. In this paper we only consider ECG, which gives a representation of the heart's electrical activity. Electrocardiograms can be used to obtain the HR (the number of times per minute the heart contracts). The oscillation in the interval between consecutive heart beats (RR intervals) as well as the oscillations between consecutive instantaneous heart rates is called Heart Rate Variability (HRV). HRV is a well documented marker in cardiology and physiological studies [2]. HRV analysis is based on measuring variability in heart rate; the distance in time from one heart contraction and the following (RR) is used to proceed in the time and frequency analysis of the HRV.

The RR intervals in ECG were used to construct a heart rate. There are several measures that can be used – in particular the mean heart rate, the HRV (standard deviation) and NN50 (the number of pairs of adjacent RR interval differing by more than 50 ms). These measures were collected during each study for three subsets of the duration of the experiment. These subsets were for the baseline period (1.5 minutes of silence and inactivity in the dark), the training (while training the participant in VR navigation) and the experimental period (3 minutes). Of greatest interest were the baseline and experimental periods.

Meehan, et al. [18] used physiological responses to measure how believable the experience of being at the edge of a pit was for the participants in his study. The hypothesis was that if the participants felt present in the room, the virtual pit would have been able to evoke physiological responses similar to those of a corresponding real environment. They note that heart rate and skin conductance measure the arousal of the individual, therefore might only be used when such arousal is intrinsic to the task, i.e. fear.

Other experiments have shown that GSR and HR could be used as objective measures in monitoring reaction in VEs [15]. Recent work [4, 21] showed that physiological measures can be used for event-correlated analysis, in particular in relation to BIPs. The detection of different properties in the physiological responses in the vicinity of an interesting event is a new strategy employed in objective presence measurements.

6. Results

6.1. Data variables

The independent variables in this study are variety of textures (repetitive textures and non-repetitive textures) and visual realism of characters (CF and HF). The explanatory variables collected a range of demographic data including habits such as experience in computer games play and physiological measures. The response variables collected using an online questionnaire was as follows.

- Presence as measured by the SUS questionnaire [23, 24] which is the count of the number of "high responses" out of 5 questions.
- Presence based on the 6 questions derived from the ITC-SOPI questionnaire [16] but using the high score count criterion.
- BIPs which is the number of reported breaks in presence.

In this study a 7-point Likert-type scale was used to gather responses to all the questions where 1 corresponded to strong disagreement and 7 was strong agreement. A score of 6 or 7 was counted as a high response.

6.2. Methods of analysis

One of the methods of analysis used on the data collected in this study was logistic regression. This is a conservative method of analysis, and has the advantage of never using the dependent variable ordinal questionnaire responses as if they were on an interval scale. The response variables are thought of as counts of "successes" in a number of trials corresponding to the number of questions, and therefore under the null hypothesis of no relationship between the explanatory and response variables have a binomial distribution, as required in logistic regression. In the case where the right-hand-side of the regression consists of only two factors (in the case the variety of textures used and the type of character) this is equivalent to a two-way ANOVA but using the more appropriate binomial distribution rather than the Normal. When covariates are included, then this is equivalent to Two-Way Analysis of Covariance (again using the binomial logistic model).

In this regression model the *deviance* is the appropriate goodness of fit measure, and has an approximate Chi-squared distribution with degrees of freedom depending on the number of fitted parameters. A rule-of-thumb is that if the deviance is less than twice the degrees of freedom then the model overall is a good fit to the data (at the 5% significance level). More important, the change in deviance as variables are deleted from or added to the current fitted model is especially useful, since this indicates the significance of that variable in the model. Here a large change of deviance relative to the Chi-Squared distribution indicates a significant contribution of the variable to the overall fit of the regression model

6.3. Basic findings

Table 2 and Table 3 give the mean presence scores using the high responses count method as collected using the SUS and the ITC-SOPI questionnaires respectively.

	CF Characters	HF Characters
Repetitive Textures	2.2±2.04	0.4±0.70
Non-Repetitive Textures	2.3±2.26	2.3±1.77

Table 2: Mean of Presence (SUS) (maximum score = 5).

	CF Characters	HF Characters
Repetitive Textures	3.9±2.28	2.4±0.97
Non-Repetitive Textures	3.4±2.27	3.6±1.71

Table 3: Mean of Presence (ITC-SOPI) (maximum score = 6).

Note the similarity between the two sets of results. These scores are not inconsistent with the results of the previous studies [12]. The lowest reported presence occurs in the virtual environment with repetitive textures and higher fidelity characters. Previous results indicate that what is required is consistency [12, 30].

6.4. Analysis of covariance on the presence scores

In this section we give the formal analysis of the binomial logistic model described in section 6.2 for the reported presence scores. Each of the independent variables and the interaction effect is significant, as is obvious from Table 2.

The overall model has deviance = 132 on 36 d.f. (i.e., the overall model is not a good fit). This model includes the main factors (variety of textures and visual realism of the characters) and the interaction term Texture•Character• Deletion of the interaction term increases the deviance by 10.72 on 1 d.f. is the tabulated Chi-Squared value on 1 d.f. at 5% is 3.841 and therefore this term highly significant. This strengthens the impression given by Table 2, which is that HF characters with repetitive textures give the lowest reported presence.

When additional explanatory variables are factored into the analysis, the following variables become significant.

- **Game-time:** The number of hours a participant spent in playing computer games is positively associated with reported presence (change in deviance on 1 d.f. = 7.73).
- **Real-behaviour:** This is the perceived behaviour realism of the characters. It is very highly significant (deviance = 27.12 on 1 d.f.) and positively associated with presence. In other words the more that behaviour was *perceived* as being real, the higher the reported presence. This is the most significant factor of all, contributing the greatest to the overall fit. It is important to note that the behaviour was the same for all the conditions in the study.

When all of these factors and variables are included in the model for reported presence, the overall deviance is 97.3 on 34 d.f., still not a very good overall fit, but much better than only using the independent variables.

6.5. BIPs

In the original paper [23], Slater et al. did not use the number of BIPs directly but rather had to take into account whether overall 'presence' was high or low. For example, if a person reports 0 BIPs this may be because they were never present or present all the time. It is important to know which side of the divide the participant falls on. As suggested in the original paper the participant was asked a question immediately after their experience in the street to rate whether their overall presence was in the street, the real world of the laboratory or about 50/50.

So as a rule if the participant felt less than 50% of the time in the street then the adjusted number of BIPs determined as the maximum number of BIPs minus the reported number of BIPs. In this case, highest BIP score was 13. This is a much simpler procedure for correcting for 'high/low' presence than the one used in the original paper [23], but does exactly the same job of reversing likely low presence BIPs, without the need for introducing an artificial time interval for a BIP as in the original paper.

A regression of the presence score from the logistic regression model on the adjusted number of BIPs was significantly and negatively correlated with reported presence (deviance = 14.53 on 1 d.f). However, unlike in [4] there was no correlation between the actual number of BIPs and the reported presence. If we take the actual number of BIPs as the response variable then it is significantly and negatively associated with the difference between the experimental NN50 score and the baseline NN50 score (deviance = 3.857 on 1 d.f.). This lends support to the proposition in [21] that breaks in presence are associated with physiological changes. There was no association between the texture and character factors and the number of BIPs. There were also no variations found in the heart rate measures across the varying conditions.

7. Discussion

The main result of the experiment was that the condition with repetitive textures and higher fidelity character representations produced a lower reported presence response from the other three conditions. This means that our original hypothesis, that the level of visual realism needs to be consistent, independent of the level, is not fully supported. We had sought to expand previous results that suggest that behaviour and visual representation should be consistent. It had been suggested in [12, 30] that participants represented by HF characters were treated differently than CF characters. This led us to speculate that characters' being notably different in representation than the environment they inhabit, might lead the participant to think the world inconsistent and thus might lead the participant to feel less present. This hypothesis can also be seen as an extension of the "uncanny valley" hypothesis [5]. That is, that as character realism (or robot anthropomorphism in the original paper) increases, believability increases, until realism reaches a point at which inconsistencies start to disturb believability. With multiple elements in the environment, there might be an "uncanny valley" for each of them, in which case designers have to be careful not to fall into any of the "valleys" because this might disturb the overall believability. The uncanny valley hypothesis would suggest that, when presented with more visually realistic characters, participants would find any inconsistencies in character and world more noticeable and jarring, whereas with more CF characters these inconsistencies would be overlooked. This prediction is supported by our study.

What we can say is that there appears to be an interaction between the levels of realism. We would suggest that our understanding of what constitutes a "level of realism" is not well developed. There are many different types of visual properties that could be changed. It may be very hard to make the judgement about whether the visual appearance of different elements is consistent. In our environment, the levels of realism in the world were different only in the repeating nature of textures. In designing the experiment, we had to be careful not to vary the visual appearance of the world too much because, for example, simply removing the textures would have meant that one world was lacking texture gradient which is an important visual cue for surface normals.

A final point to make is the highest significant subjective measure in the study was the participants' perceived sense of realism with respect to the behaviour of the characters. The more a participant *perceived* the characters behaviour to be real, the higher the reported sense of presence. This strengthens the views reported in previous studies [12, 30].

8. Conclusion and future work

In this paper we have presented a study that started to examine whether different elements of a virtual environment need to be presented with consistent levels of detail. Several authors have suggested or shown that there needs to be a match between visual appearance and behaviour of characters. However important characters are for the scene, they are placed with a space that also has visual appearance and behaviour. It is therefore logical to suggest that different elements need to be presented at similar levels of detail in order that no-one element is notably inconsistent from the others.

In a case-based experiment we started to study this for populated urban environments. We had two conditions of texture detail on the buildings, and two of levels of visual realism of characters populating that space. We found that within one of these conditions, "low texture detail" and "high visual realism of characters", the participant's reported presence was notably different from the others. This doesn't confirm the original hypothesis that visual appearance between elements needs to be consistent, but we have discussed that it is very hard to determine visual consistency, and there may be other interactions other than consistency between the different conditions.

We suggest that this area deserves further work, because it could indicate useful criteria by which to start discriminating between contributions of different elements in a scene to the overall sense of presence. Previous work has treated presence as a single response to an experience, whereas that experience is composed of interactions with many different elements with widely varying attributes. Work on BIPs has indicated that participants can be very sensitive to small inconsistencies, so it is worth developing an understanding of how those inconsistencies might arise. Furthermore, since an increasing proportion of the effort in building VEs today goes to modelling elements in the scene, it will be important for designers and engineers to have guidelines about consistent levels of detail, so that, the appropriate design choices can be made. Specifically, if consistency is really an issue, we would like to avoid investing too much effort in the construction of particular element in a scene if it would then be inconsistent with the other elements.

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